Quantifying Sediment Volume Inhomogeneity for Modeling High-Frequency Acoustic Backscatter

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LONG-TERM GOAL

As part of ONR's Sediment Acoustics EXperiment (SAX 99), the long-term goal of this research is to develop an approach for deriving acoustically relevant descriptions of seafloor sediments for modeling high-frequency sound scattering.

OBJECTIVES

Our primary objectives for FY99 have been as follows:

1. Provide a quantitative preassessment of the three-dimensional structure of sandy seafloor sediments in preparation for the SAX99, scheduled for October-November 1999, off Fort Walton Beach, FL. To do this, we used existing data for similar sediments collected during the 1993 Coastal Benthic Boundary Layer (CBBL) exercise off Panama City, FL.

2. Develop an approach to derive realistic input parameters for the development of accurate acoustic scattering models. Investigations have included the construction of high-resolution density profiles and the characterization of sediment volume inhomogeneity.

APPROACH

X-ray computed tomography (X-ray CT) is being used for core characterization in this research. Developed over 30 years ago by the medical industry to generate cross-sectional X-ray images of the brain, X-ray CT is a powerful analytical technique, well-suited for high-resolution geoacoustic

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characterization of marine sediment cores. It is non-destructive and quantitative, has sub-millimeter resolution, and permits two- and three-dimensional visualization of sediment structure.

WORK COMPLETED

1. Preassessment of the Panama City cores has been completed (Figure 1) and the results of our analysis in terms of the power spectra of density variability have been accepted for publication in the Journal of the Acoustical Society of America (Tang and Orsi).

2. A calibration procedure has been developed for X-ray analyses of marine sediments. A manuscript describing the approach is in press (Orsi and Anderson).

3. Using several existing CT data sets, we completed an examination of the impact of a thin layer of varying density on high-frequency reflection, forward loss, and backscatter of acoustic plane waves from the seafloor. The results of this analysis have been published in the IEEE Journal of Ocean Engineering (Lyons and Orsi).

4. We have also prepared a general interest article on the CT analysis of seafloor sediments that has been submitted to Sea Technology (Orsi et al.).

RESULTS

1. Spectral analysis of the sandy Panama City sediments reveals three mechanisms causing density variability: shell fragments, mud inclusions, and the intrinsic variability of the sand matrix (which is consistent with a Gaussian distribution). Shells and the mud inclusions dominate the low-wavenumber portion of the spectrum, whereas intrinsic matrix variability dominates the high-wavenumber portion. The inferred spectrum is well described using an analytical model with two power-law terms. The exponent of the first power-law term is much higher than previously believed. In the case of backscatter, the relationship between the power spectrum and acoustic frequency shows that between 10-100 kHz, backscatter will be strongly influenced by the presence of the shell fragments and mud inclusions, whereas intrinsic variability influences backscatter at frequencies above 400 kHz. In addition, when the frequency is lower than 70 kHz, the backscattering cross section behaves like that of a Rayleigh scatterer.

2. A calibration technique was developed for converting CT numbers to equivalent sediment bulk densities. Derived using artificial samples and confirmed with natural marine sediment samples, the correlation for carbonate-free samples is extremely strong and valid over densities from 1.0 g/cm^3 to 2.2 g/cm^3. A similar analysis of carbonate samples and sediment cores was also strongly linear but offset from the silica curve, a result of differing sediment composition. (Further development of the CT number-carbonate relationship would be a valuable research topic.) Density resolution of the CT scanner is excellent and estimated to be 0.005 g/cm^3. Greater precision is not warranted because density variations in this range of sensitivities can be affected significantly by thermal fluctuations.

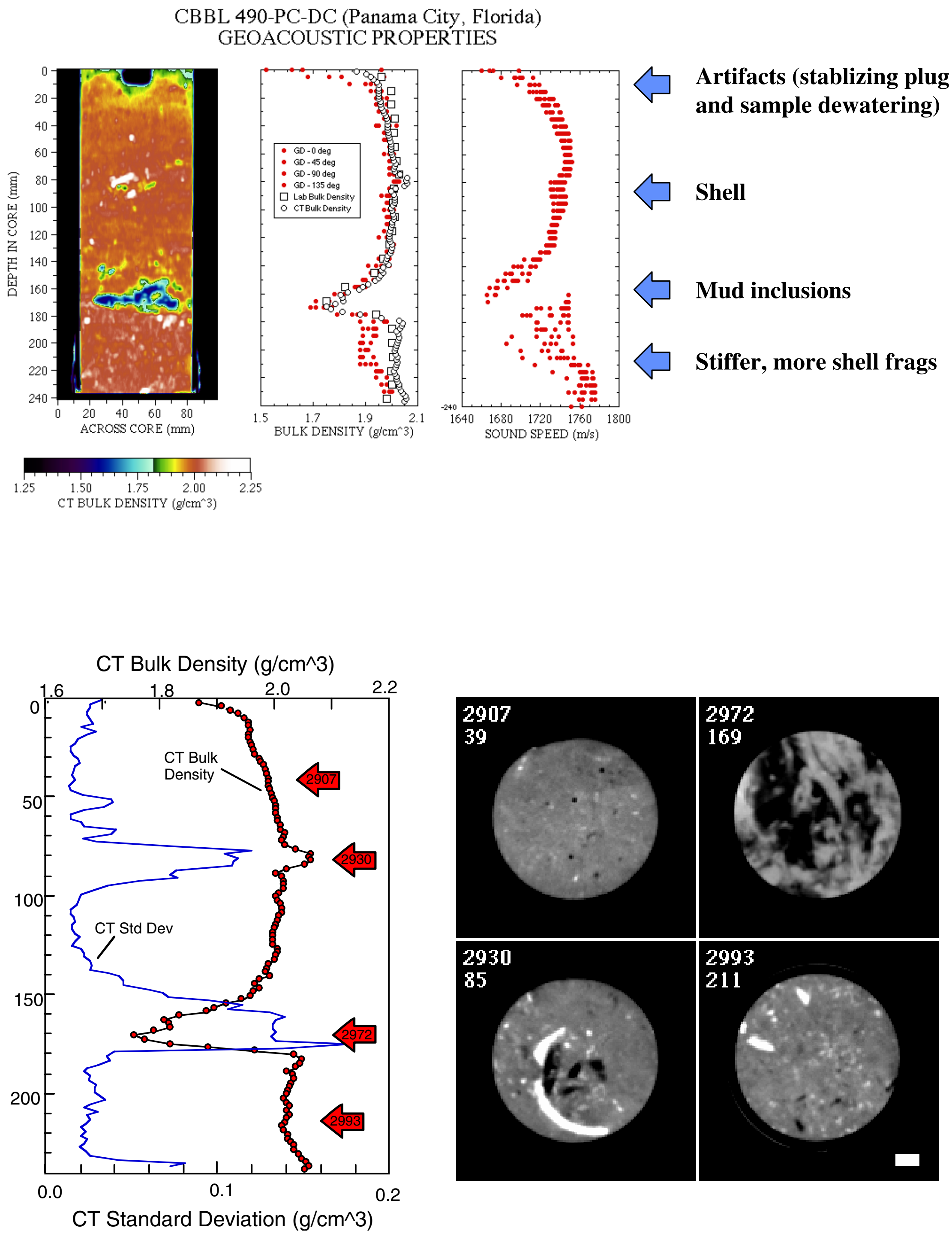

Figure 1. Example of the CBBL Panama City dataset. Scale bar = 1 cm.

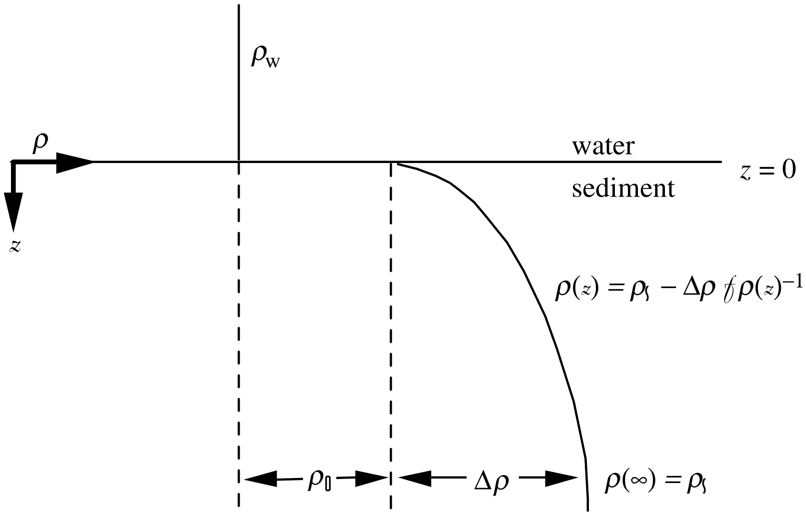

Figure 2. CT-derived seabed layering model for density with $f_r = 1 + az$. Density approaches r_s with depth according to the function, $f_r = 1 + az$. (We refer to the parameter, a, in this equation as the density profile parameter which is a measure of the thickness of the high density gradients in the combined mixed and transitional layers.)

3. To quantify the impact of a thin layer of varying density on high-frequency acoustic response, we devised a functional form for density stratification using CT (Figure 2). We found that inclusion of a high-resolution density profile adds a strong frequency dependence to estimates of the reflection coefficient and forward loss, and the largest effect on total scattering strength is near normal incidence where returns are dominated by interface scattering. The effect of the density profile on the strength of acoustic returns suggests that care should be exercised when using high-frequency systems for measuring sediment properties, especially near-normal incidence.

IMPACT/APPLICATIONS

Development of accurate, quantitative, and appropriately scaled seafloor descriptions via CT analysis will eliminate modeling ambiguities associated with uncertain sediment structure and permit calculation of statistical descriptors, e.g., correlation lengths, property variances, subsurface interface spectrum, and property anisotropy (if present) on any plane within the seafloor.

TRANSITIONS

Historically, one of the more difficult tasks in modeling the interaction of high-frequency sound with the seafloor has been developing realistic descriptions of the sediments with all their complexity. This complexity is often readily apparent in any sediment core or x-radiograph. Fortunately, CT analysis is uniquely suited to enable the transition of qualitative and semi-quantitative geologic information to the quantitative input parameters needed by acousticians for modeling acoustic scattering.

RELATED PROJECTS

In a related effort, we are participating in the SACLANT Centre's FSG-DERA-JRP-2 experiment in the Bay of La Spezia (Co-Chief Scientists: T. Lyons and E. Pouliquen). For this exercise, we have been using CT analysis of diver-collected horizontal cores to examine volume inhomogeneity in both the vertical and horizontal dimensions. Our analysis continues.

PUBLICATIONS

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